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ABSTRACT

Performance becomes degraded when the human processing system undergoes the stress of processing overload. Information processing models are often used to predict how performance will be affected. Single channel models hypothesize that information will either be lost in the queue or processed with delay. Single capacity models predict that for a single task a speed-accuracy function can describe performance, and that for dual tasks performance-operating-characteristic-functions can describe performance. Multiple channel models suggest that any process can be degraded when a channel is overloaded even though other processes could be carried out by other channels. Multiple capacity models predict that speed-accuracy functions and performance operating characteristics can be found for processes that require the same capacities, but, depending upon the capacity requirements of each task, the task can trade off in many ways. The emotional reaction associated with stress may require processing resources and acts like a separate sub-task compounding the overload problem. The type of processing required of operators monitoring system status in automated systems may draw from the same resource pool that supplies resources for dealing with stress. When new strategies are needed to allocate attentional resources, the effects of stress seem to be particularly detrimental. (Author)

PERFORMANCE DURING THE STRESS OF PROCESSING OVERLOAD

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Performance During the Stress of

Processing Overload

This paper considers the effects on performance of stress that is endogenous to the task being performed. Usually this type of stress is due to processing overload. In predicting how performance will be affec^ted we often rely on information processing models. By specifying the limits of the processing system, we can hypothesize how the system will perform when these limits are exceeded.

One of the earliest models proposed (shown in Figure 1) was the single channel model usually attributed to Welford (1952) or Broadbent (1958). This is a structural model in that at some point in the human system there is a bottleneck that allows only one task to be processed at a time. Other tasks must wait in a queue until the channel is empty.

Investigators have place this bottleneck from early in the system at a sensory level (Broadbent, 1958) to very late in the system after much analysis of input has taken place (Deutsch & Deutsch, 1963). Others have suggested that the human can choose from among a number of alternatives where to put the bottleneck depending upon the breadth of information sources to be considered and selection efficacy (Johnston & Heinz, 1978). Regardless of channel location, the obvious result of processing overload for single channel systems is either that information is delayed in the queue so that response latencies are increased or else that information delayed to the point it is degraded or lost.

The second major type of model (shown is Figure 2) is the single capacity model (Moray, 1967, Kahneman, 1973). In this case a central resource pool is available for energizing processes. In the model's

most general form, the resources available are non-specific; that is, they can be used to handle a variety of processes. However, the resource pool has a fixed limited capacity. When the resources are exhausted, the processes receiving no resources or inadequate resources are either not carried out or are carried out with loss of efficiency.

If we look at performance for a single process that has received an insufficient allotment of resource, then we have what has been called a resource limited process (Norman & Bobrow, 1975). For that process, performance can be degraded by sacrificing either speed or accuracy. Hence, we could produce a performance function for that single process by inducing the subject to adopt a number of speed-accuracy tradeoffs (Wickelgren, 1977). Figure 3 shows a typical speed-accuracy curve from an experiment by Dosher (1976).

If we measure only one performance index for each process (holding the other constant), then we can show how one process can tradeoff with another process. That is, by manipulating payoffs or instructions we induce the subject to allocate various proportions of resources to one process at the expense of another. Here again, a performance function, such as the idealized function shown in Figure 4, can be found, but in this case, the function shows how the processes tradeoff. This function has been called a performance operating characteristic (Norman & Bobrow, 1976) or attention operating characteristic (Sperling & Melchner, 1978).

To completely specify what happens to performance on a particular task during overload it would be necessary to determine a three dimensional surface, where the dimensions are speed and accuracy for that task and the third dimension is resources devoted to that task.

Within single capacity models the situation may be even more complex than this if some processes can be performed automatically as suggested by Schneider and Shiffrin (1977). They present evidence that certain tasks when highly overlearned appear to require no resources from the central pool. For these tasks then we would predict no stress in a multi-task situation, since no overload could occur.

The third general class of models has been called multiple channel models (Allport, Antonis, & Reynolds, 1972) or multiprocessor models (McLeod, 1977). These models, such as the one illustrated in Figure 5, regard the information processing system as a series of independent processors operating in parallel. If tasks require none of the same processors, they could in principle be performed simultaneously without mutual interference. Similar tasks, particularly those using the same sensory modality, are likely to use the same channels or processors. Since a channel can process only one task at a time, information sources for similar tasks must wait in queue, much like in the single channel models.

According to strict multiple channel models then, if the tasks to be performed in a multi-task situation are dissimilar, we should find no overload and therefore, no interference. The more similar the tasks, however, the more likely they require the same channel and then we would expect the same type of performance degradation specified for single channel models.

The final class of model has been called multiple cacpacity models (Navon & Gopher, 1979). Rather than having a single central resource pool, this model hypothesizes that we have many separate resource

pools or capacities. Any task may require resources from several of the pools and as long as adequate resources are available in the pools other tasks requiring these resources may also be performed (although possibly in a degraded manner). Thus, processes that use the same mechanisms may interfere with each other but seldom block each other completely. Figure 6 illustrates a multiple capacity model and shows the way units of resources can be allocated to various processes.

In the more flexible form of this model it is also possible to use resources from less appropriate capacities to substituute for those from the more appropriate capacity if resources from the appropriate capacity have been exhausted. However, more of these less appropriate resources must be used to carry out the same processes, so overall efficiency decreases.

The multiple capacity models would seem to be able to account for any type of performance in a multi-task situation. No interference occurs when resources from different capacities are required. Linear tradeoffs can occur if the tasks require the same proportion of resources from each capacity. Nonlinear tradeoffs of all kinds can occur if tasks require different portions of resources from each capacity or if less efficient resources must be substituted. And complete blocking, such as in the single channel models, can occur when a task exhausts the resources of a capacity and other resources are not substitutable. So, while we are now able to explain all types of performance, these explanations are post hoc and the model gives us little predictive utility unless we can determine a priori which tasks use which capacities, how many capacities there are, and how large each capacity is.

If human behavior is best described by the fourth model, how can we ever make predictions about the effects of overload on performance? Fortunately for many operational multi-task situations the structure of the operations required, constrain the way the human can respond. In these cases we can make some simplifying assumptions that allow us to use one of the first three models to predict performance.

For example, I am currently investigating how an operator chooses strategies for sampling information from spatially separated visual displays. The operator's job is analogous to the aircraft pilot sampling information during instrument flight. In this case, we can assume that the operator is acting like a single channel model because the structure of the task itself places a bottleneck at input. It is then possible to predict performance using queueing models (Senders & Posner, 1976). Thus, while the operator could probably perform like the fourth model given the proper situation, this task forces him to perform like the first model.

On the other hand, consider a situation in which the information for the various subtasks is presented by means of different sensory modalities such that structural input interference is minimized. In addition, suppose that the processing required by the subtasks is quite similar so that the same resource pool is being required by each of them. In this case we would expect the operator's performance to be adequately predicted by the single capacity model. Much of the research that has demonstrated the effectiveness of dual task procedures has been of this type. It is probably because researchers chose this type of situation to investigate that the single capacity model gained such widespread acceptance.

Some recent research by Rollins and Hendricks (1980) also indicates that for some shadowing tasks, multiple channel models can best account for the data. The channels in this case are specific to type of analysis, e.g., semantic analysis and acoustic analysis, and to modality, e.g., visual semantic analysis and aural semantic analysis.

To summarize our ability to predict overload performance from models, the human operator is so flexible that performance can breakdown in many ways making a priori prediction of performance quite difficult, however the structure imposed by the tasks will often allow us to infer one of the simpler models. These simpler models do permit us to predict how performance will be affected by processing overload.

The information processing models I have been describing account for performance decrements strictly in terms of either the structure of the human system or the strategy the human chooses. The models make no attempt to account for the effects on performance of emotional reactions to overload. We certainly realize that some people can remain "cool" under processing overload while others become "panicked" and perform poorly. Introspectively it seems that even for the same person some overload tasks are more stressful and cause larger performance decrements than other tasks. How can we incorporate these emotional responses into our models?

One way to conceptualize the emotional reaction is to consider it a separate subtask. Sachs, Martin, and Moyer (1977) suggested such an interpretation for a conditioned emotional responding experiment. In this experiment human subjects were first conditioned by hearing a tone followed repeatedly by a painful electrical shock. After conditioning, subjects attempted to successively subtract three from a starting

number and in some conditions also tracked a rotating disk with a stylus. Number of correct responses and time on target were recorded both during tone intervals and blank intervals. The basic result was that the number subtraction task showed a decrement in performance for the intervals during which the tone that signalled the aversive event was present. This result was interpreted within an information processing framework. That is, the authors felt that the processing required in preparing for the aversive event apparently impeded the subject's ability to perform the subtraction task.

While this experiment illustrates the effects on performance of emotional reactions to what I would call exogenous stress, we should be able to use similar techniques to measure the effects of endogenous stress.

Endogenous stress occurs when the human becomes overloaded by information processing requirements. Generally this situation occurs when several tasks must be performed concurrently such as when a pilot flying by instruments must monitor many sources of information. If the sub-tasks are each well learned and the pilot has developed a successful attention allocation strategy for normal flight conditions, endogenous stress will be minimized. However, should conditions change, particularly should they take on levels that the pilot is unfamiliar with or has not practiced, then he will have to determine a new allocation strategy. It would seem that the reallocation of attention and the devising of new allocation strategies would require large unplanned expenditures of processing resources interrupting on-going processes and thereby producing stress.

One way of reducing such endogenous stress might be to train

pilots, or the operators of any system that potentially requires the reallocation of attention, how to make such decisions under such uncertain conditions. In my laboratory we are presently developing and testing a general purpose visual monitoring task for determining if such training is possible and how the training might generalize to operational systems.

At the moment, we have a computer generated matrix of six cells. In each cell location, single digit numbers can occur. The operator is required to respond to certain of these numbers in each of the cells. For each cell four parameters can be specified: task difficulty (i.e., the information reduction required by the signal), the probability a signal will occur, the time allowed for responding, and the cost of failing to make a response in the allotted time.

Using this general task, we are investigating a number of questions: When the parameters are specified, how good are humans at devising allocation strategies compared to optimal math models? What type and how much processing resources are required when reallocation of resources is required to either a previously learned parameter set of to a new parameter set? Does training an operator to devise new allocation schemes help him when he transfers to an operational setting that requires such an ability? Our general concern is that it may be the requirement for reallocation of resources that first of all causes serious endogenous stress and that it then may be this reallocation performance that is most affected by the stress. This vicious circle may, in fact, be especially critical in modern automated systems in which the operator's task is monitoring system status under changing conditions.

Wickens and Kessel (1980) have reported that operators attempting to detect a change in system tracking dynamics when tracking is accomplished in an automated mode use resources from a different resource pool than when detecting changes while in a participatory manual mode. Detection efficiency in the automated mode was degraded by a mental arithmetic loading task but not by a tracking loading task. The result was reversed for the manual mode. The authors interpreted these results within the framework of a multiple capacity model, and suggest that the automated detection task relies exclusively on processing resources associated with perceptual/central-processing stages. The manual task in contrast apparently relies on a response-related processing pool.

These findings fit nicely with the Sachs et al. result in which the stress associated with an aversive event degraded a number subtraction task but not a tracking task. In combination, the results indicate that the processing resources required in dealing with emotional stress are drawn from the same pool used for the important perceptual/central-processing functions required in highly automated systems. In addition, it is likely that the decision making required for resource reallocation mentioned earlier in the paper also uses resources from this pool and thus would be affected by exogenous stress and probably also by endogenous stress.

At this point, we are left with a number of interesting but unanswered questions.

1) Is it true that stress, either endogenous or exogenous draws largely from a perceptual/central resource pool?

2) Does the process of resource reallocation itself draw largely

from this same pool?

3) Can we train the general ability to reallocate resources so that reallocation is less affected by stress?

4) Can we train operators to cope with stress in ways that draw fewer resources from the perceptual/central resource pool?

Obviously we have just begun to investigate these questions. However, the models that have been proposed within an information processing framework and the dual task methods that have recently been developed should permit us to answer such questions.

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Single Channel Models

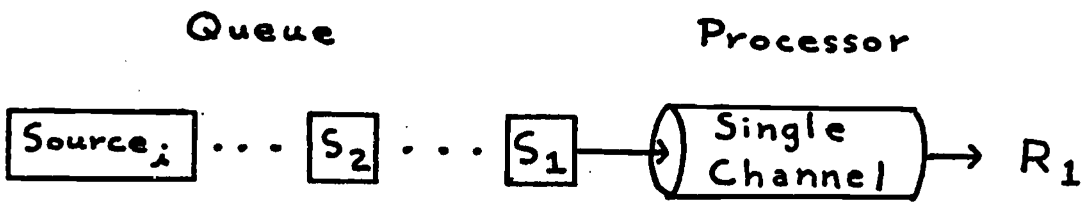


Figure 1

Single Capacity Models

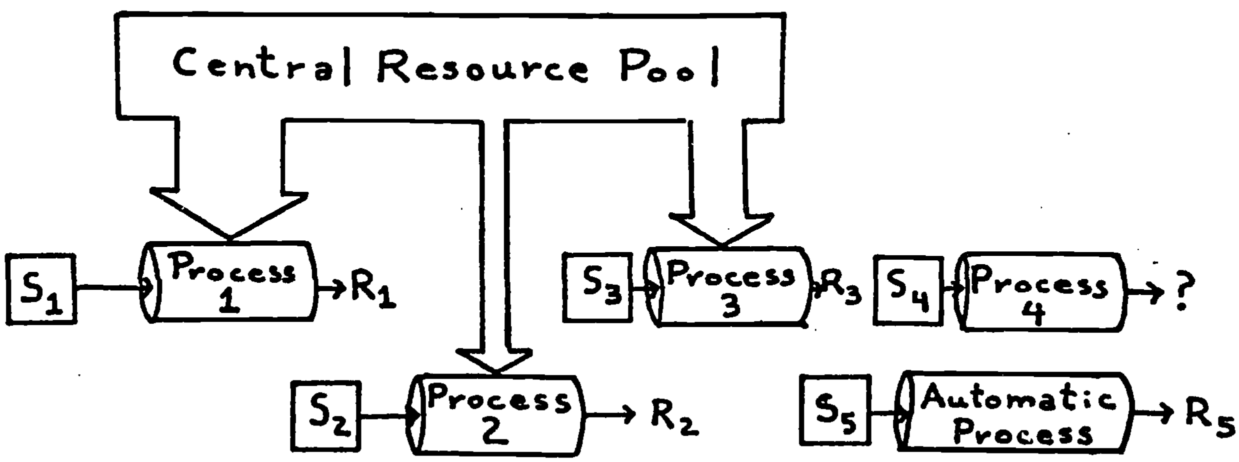


Figure 2

Multiple Channel Models

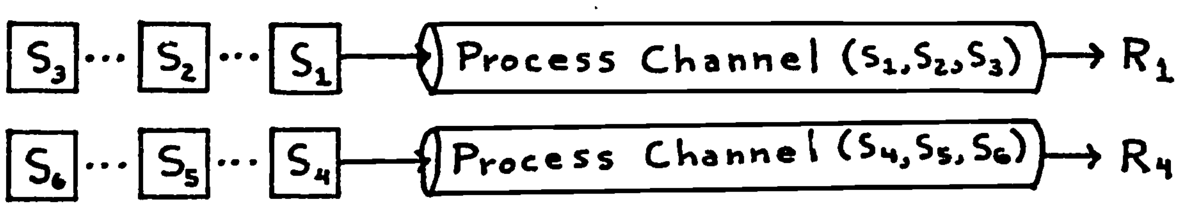
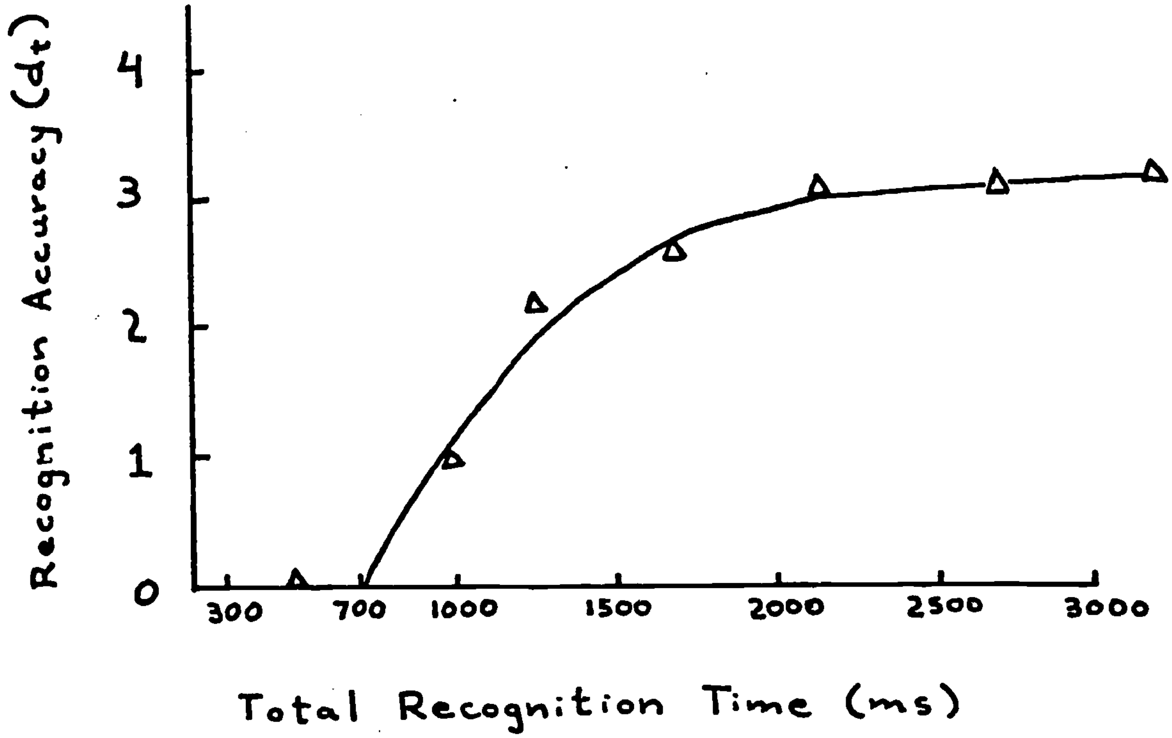


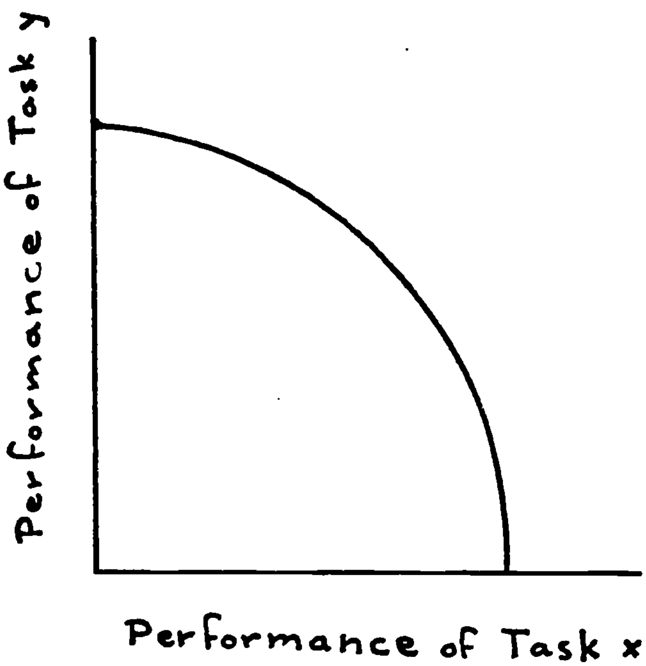
Figure 5.

Speed-Accuracy Curve



[from Dosher (1976)]

Figure 3.



[from Navon & Gopher (1979)]

Multiple Capacity Models

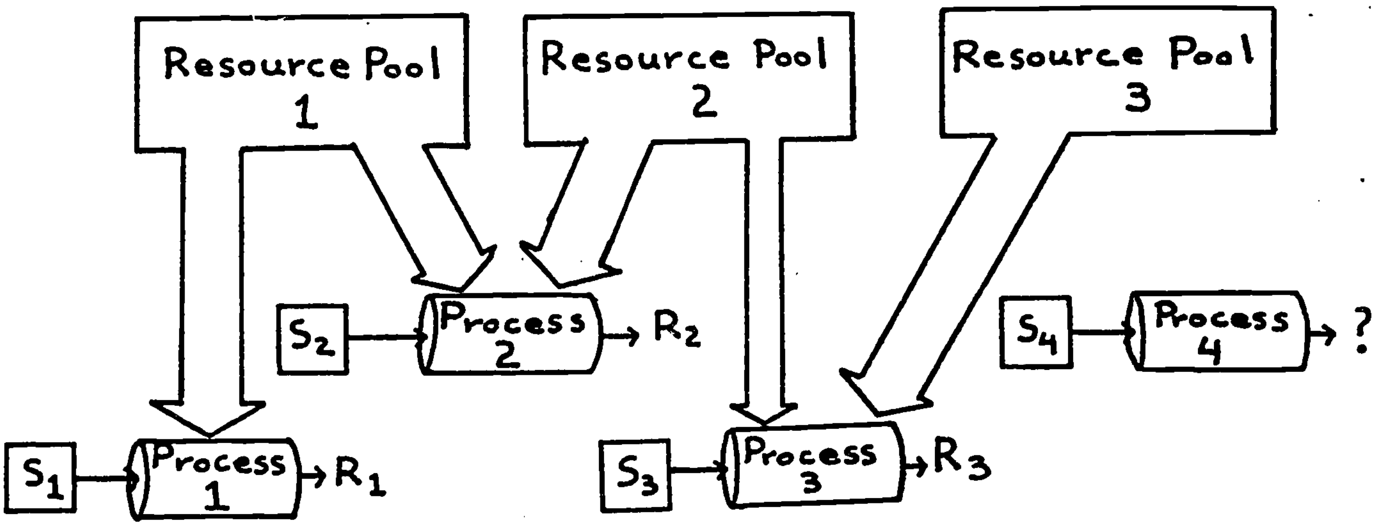


Figure 6.